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RESEARCH, DEVELOPMENT, TEST & EVALUATION SECTION

Evaluation of Acceleration Response during AFRL $+G_z$ Vertical Deceleration Tower Tests

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ABSTRACT

An analysis and comparison of impact acceleration responses in male and female pilot subjects is presented. This study is motivated by the increasing number of gender-related laboratory tests to determine if males and females respond differently to the high impact accelerations simulating in-flight ejection from military aircraft. Acceleration response data are analyzed and compared using vertical drop tower tests from Study No. 199906 conducted by the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base, Ohio. Acceleration time histories at the seat pan, T1 (1st thoracic vertebra), head and chest, were recorded for +Z axis impact accelerations of 6, 8 and 10 G's. The results demonstrate that males and females respond similarly to ejection-like impacts. The greatest percent difference in peak acceleration response between male and female subjects in the 10 G test occurs in the chest at 9.2%, followed by the T1 and head at 8.1% and 4.8%, respectively. All differences have p-values of ≤ 0.05. With uncertainty, however, the difference between male and female values might not exceed 4% at any location. Smaller differences between genders are found in the time-of-peak ($\leq$ 2.5%). Minimal correlation is found between mass or sitting height with the magnitude of peak acceleration or time-of-peak. All correlations are $r \leq 0.26$. A stronger correlation of $r = 0.84$ is found between subject mass and sitting height for all subjects. This independent study of the AFRL data confirms many previous conclusions while establishing additional insights into this unique set of experimental data.

INTRODUCTION

Since the recent introduction of females into combat aircrew positions, a number of questions have arisen concerning the risk of spinal injury in females, especially during the initial stages of in-flight ejection when seat acceleration is highest. These concerns are valid since most impact tests and evaluations to determine risk of ejection injury were conducted for a 50th percentile of the male pilot population and a smaller range of pilot sizes. Not until the late 1990's did testing of females in ejection-like loads occur.

Engineers of the Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base in Dayton, Ohio, are leading the investigation of female response to impact accelerations, especially through the many experiments and data collected at their vertical deceleration tower (VDT) facility. To date, experimental studies of ejection-like impacts have shown no significant differences in spinal response between male and female subjects. One of the first published studies Buhrman and Mosher (1999) evaluate male and female subjects exposed to vertical impact acceleration pulses. The magnitude and duration of the subjects' acceleration responses are measured and compared, and analytical techniques are used to compute the undamped natural frequency and damping ratio for each subject. The results demonstrate similar magnitude and duration of the chest acceleration response in males and females, with small differences in the undamped natural frequency as a function of subject weight.

Burhman and Wilson (2003) compare bone mineral density (BMD) and vertebral stress between male and female pilot subjects using Quantitative Computed Tomography (QCT). The results demonstrate no significant differences in either BMD or vertebral stress between males and females, but found that taller, lighter individuals of both genders experience slightly less stress than shorter, heavier individuals.

Siedlecki et.al. (2002) show strong correlations between various anthropometric measurements and vertebral body size in male and females. Regression equations are established to provide estimates of vertebral body cross-sectional area to within 10% of measured values. These estimates are valuable as they can be used in conjunction with current biodynamic models to evaluate and minimize the risk of spinal injury in both males and females.

Morris and Popper (1999) report experimental measurements of bracing against non-vertical impact accelerations. An attempt is made to identify a correlation between gender, braceablity, static strength, anthropometric measurements, or combinations thereof. It is concluded that no useful correlations exist and that gender is not found to be a factor in predicting non-vertical impact accelerations.

Despite the work that has taken place in the last few years, experimental data from a number of vertical deceleration tower (VDT) tests conducted at the AFRL, demonstrate noticeable differences in upper body response among subjects. Whether these disparities are due to physio-logical size or gender differences has not yet been established. Data often shows peak accelerations and times-of-peak varying as much as 30% among individual subjects, giving credibility to the theory that significant differences do exist between genders. Furthermore, a comprehensive ejection injury database has not been compiled for females. Since females have an average 30% less body mass than males, a spine that is 10% shorter, a 25% reduction in vertebral cross sectional area and a 20% reduction in vertebral breaking threshold, it is imperative that further analysis is conducted to isolate spinal response difference between genders. If no significant difference exists, attention should be given to why this condition exists despite the obvious anatomical gender differences discussed earlier.

The objective of this study is to analyze live human response data from vertical impact accelerations of twenty male and twenty female subjects of various anthropometric dimensions, under identical initial conditions. The effects of subject gender and anthropometry on human response to impact and vertebral loading will also be investigated. The results might lead to the development of more robust biodynamic models that will be useful in predicting probability of injury to the female flying population during the early stages of in-flight ejection.

AFRL BIODYNAMICS DATABASE

Experimental data used in this study is taken, by permission, from the AFRL Biodynamics Database under Study No. 199906. Forty-five human subjects are voluntarily exposed to vertical acceleration pulses at presumed noninjurious levels using the AFRL Vertical Deceleration Tower (VDT). All subjects are members of the AFRL Impact Acceleration Panel and were medically qualified for VDT testing. The use of human volunteers in this experimental protocol was approved by the Wright Research Site Institutional Review Board (IRB) at Wright-Patterson AFB, Ohio.

Of the forty-five subjects tested, twenty males (n = 20) and twenty females (n = 20) of various sizes are chosen due to completeness of test data. The subjects are tested under identical conditions at 6, 8 and 10 G's. One test per subject is conducted at both 6 and 8 G's, respectively, while three tests per subject are conducted at 10 G's. The 10 G acceleration level tests are deemed more important as they are closest to the actual acceleration experienced by the body during in-flight ejection.

Sixty anthropometric measurements were taken on each subject. Of those, only four measurements proved to be of interest in this study: mass, sitting height, stature and age. These values can be found in Table 1. Subject demographics are consistent with the Air Force pilot population for allowable mass (AF standard is 46.8 to 105.2 kg), stature (AF standard is 162.6 to 195.6 cm) and age (AF male mean is 33.2 yrs, AF female mean is 29.2 yrs).

Table 1. Key anthropometric measurements ($\pm \sigma$) for the twenty male and twenty female subjects in this study.

Parameter	Males *n = 20*	Females *n = 20*	% Diff
Mass (kg)	86 ± 14	61 ± 8	-29.1
Probable Range	66 - 109	50 - 76	
Sitting Height (cm)	95 ± 4	86 ± 6	-9.5
Probable Range	88 - 105	64 – 91	
Stature (cm)	179 ± 7	164 ± 8	-8.4
Probable Range	168 - 193	146 - 175	
Age (yr)	33 ± 7	26 ± 6	-21.2
Probable Range	22 - 44	19 - 39	

A comprehensive list of details concerning the VDT apparatus and equipment used during the experiments are detailed in the AFRL Biodynamics Database. In general, the subjects were positioned in a generic seat mounted to the VDT carriage in the upright position, with the seat back perpendicular to the line of acceleration. The subjects were restrained with a double shoulder harness and lap belt and each subject wore a standard HGU-55/P flight helmet weighing 1.1 kg.

Figure 1 shows where four acceleration responses are measured: seat pan, T1 (1st thoracic vertebra), head, and chest. The seat pan acceleration can be used as a basis for the input acceleration to the body. All accelerations are measured using a linear tri-axial accelerometer package at each location and data are collected at 1,000 samples/sec.

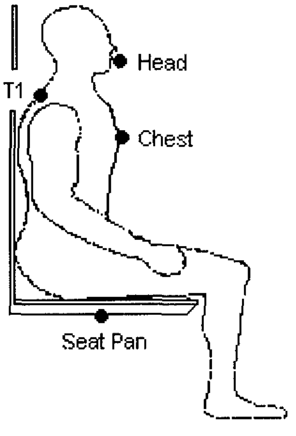

Figure 1. Locations of accelerometers commonly used in Air Force VDT tests (adapted from AFRL).

A typical acceleration response plot resulting from a VDT test is shown in Figure 2 and demonstrates accelerations in the four locations. The seat pan acceleration acts as the input and as expected, peaks at approximately 10 G. Each of the corresponding responses in the upper body exceeds the input acceleration, demonstrating the dynamic overshoot present in the human body. Of primary interest is the magnitude of peak acceleration and the time-of-peak acceleration. These parameters directly reflect the amount of displacement present at each of the locations in the upper body due to the forces of the impact. Excessive displacements cause spinal injury.

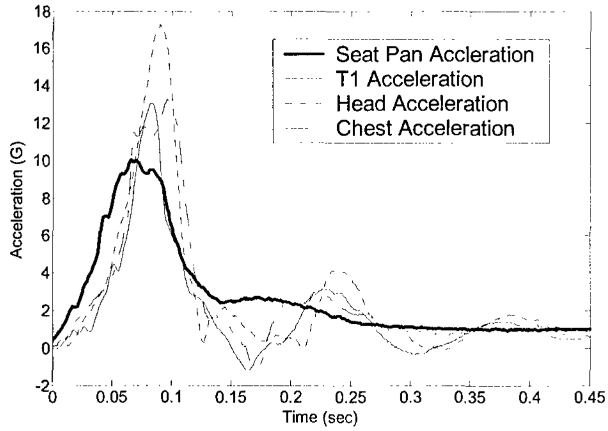

Figure 2. A typical acceleration response plot at 10 G showing accelerometer readings at the seat pan, T1, head and chest.

METHODOLOGY OF ANALYSIS

In order to characterize the acceleration data, box plots are performed on collected data for each accelerometer location and are reported in the Results. The plots show the center of each data set (median), where most data fall (1st and 3rd quartiles), the spread of unquestionably "good" data, and possible outliers. The box plots also give good relative perspective of response from one acceleration level to another. Means and standard deviations are also calculated for acceleration peak magnitudes and times-of-peak for each subject at each accelerometer location. These data are displayed in table format for all VDT tests: 6, 8 and 10 G's. Percent differences between male and female results are also calculated and displayed in each table and displayed in bar graph form. Scatter plots, with their corresponding regression lines and Pearson product-moment coefficients (r) are used to provide statistical analysis of the 10 G response data as a function of mass and sitting height.

RESULTS

In order to ensure consistency in initial conditions among subject tests, a critical look at several parameters is first required. Table 2 details comparisons between average velocities, rise times and pulse widths of male and female subjects at different acceleration levels. The percent differences in all parameters are statistically insignificant, with the 8 G test velocities showing the greatest difference of 2.7%. This anomaly is likely due to experimental error in the velocity tachometer, as all other values in the 8 G test are very small.

Table 2. Average velocities, rise times and pulse durations (± σ) at the three acceleration levels for male and female subjects.

Measured Parameter		Males *n = 20*	Females *n = 20*	% Diff
Velocity (m/s)				
Test	*6 G*	6.2 ± 0.3	6.3 ± 0.4	1.6
	8 G	7.5 ± 0.7	7.3 ± 0.6	-2.7
	10 G	8.4 ± 0.5	8.3 ± 0.5	-1.2
Rise Time (ms)				
Test	*6 G*	91.8 ± 2.4	91.1 ± 2.7	-0.8
	8 G	81.5 ± 1.3	81.4 ± 1.3	-0.1
	10 G	74.6 ± 2.3	73.6 ± 2.5	-1.3
Pulse Duration (ms)				
Test	*6 G*	163.9 ± 2.8	163.3 ± 3.3	-0.4
	8 G	152.2 ± 1.7	151.8 ± 1.4	-0.3
	10 G	145.8 ± 2.3	145.0 ± 2.5	-0.6

Anthropometry

With respect to anthropometric measurements, one significant correlation was found between subject mass and sitting height. An r-value of 0.84 exists for both male and female data. When evaluated separately, r-values of male data were better correlated (r = 0.69) than female data (r = 0.52). This finding is similar to that of Buhrman and Mosher (1999).

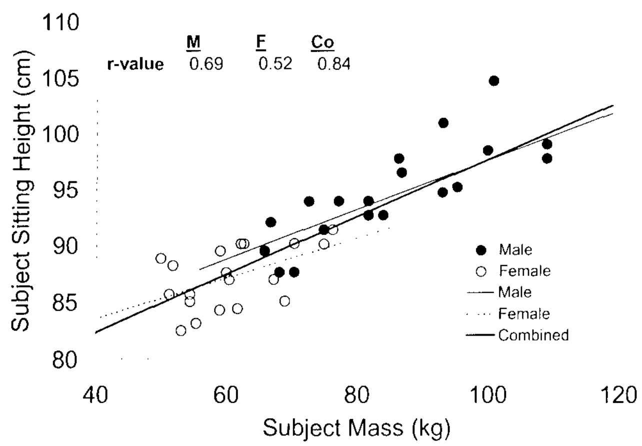

Figure 3. Sitting height vs. mass of all subjects (n = 40). Linear regression lines and Pearson's coefficients (r) are given.

Peak Acceleration

Based on the box plots presented in Figure 4, on the following page, a relative observation can be made in the variability among the data sets of the various locations. The figure displays peak accelerations for the 6, 8 and 10 G tests for 20 male and 20 female subjects. Table 3 details the data in numerical form. The measured seat pan accelerations have very little variability in peak acceleration when compared to measurements actually taken on the human body, as expected. Variations in the seat pan are minimized since the accelerometer is mounted onto the rigid seat/carriage assembly, and not on the viscoelastic body. Since the seat pan acceleration acts as an input acceleration to the human subject sitting atop the seat, the peak acceleration is shown to nearly equal the nominal acceleration of the test. Therefore, a 10 G VDT test has a seat pan acceleration of approximately 10 G. In a VDT test, this acceleration is controlled by adjusting the height from which the seat is dropped. The height is a function of subject mass. Based on the seat pan acceleration values in Table 3, it can be concluded that a negligible difference exists between male and female data at the seat pan.

As seat pan acceleration data contains the least amount of variability, the T1 data has the most. This is primarily due to the fact that the T1 accelerometer is difficult to affix to the upper back of the human subject. Variability inevitably mounts as the accelerometer's position on the upper back moves with respect to the body during testing. A further review of the data reveals that the peak acceleration at the T1 increases with increasing input acceleration. Variability in the data also increases from 6 to 10 G's. The greatest difference in peak T1 acceleration between male and female is in the 10 G test with a change of 8.1%. The T1 accelerations are also the largest of the four locations with values at or near 20 G.

Table 3. Peak accelerations data (± σ) of the three acceleration levels, for male and female subjects.

Measured Parameter	Males	Females	% Diff	p-value	N
Peak Seat Accel (G)					
6 G	5.97 ± 0.1	5.97 ± 0.1	0.0	NSD	20
8 G	8.01 ± 0.1	8.03 ± 0.1	0.3	0.02	20
10 G	10.0 ± 0.1	10.04 ± .1	0.4	≤ 0.01	60
Peak T1 (G)					
6 G	9.1 ± 2.2	9.3 ± 1.6	2.2	0.19	20
8 G	14.5 ± 2.0	13.8 ± 2.6	-4.8	0.14	20
10 G	20.0 ± 4.7	18.5 ± 2.5	-8.1	0.03	60
Peak Head (G)					
6 G	8.6 ± 1.3	8.5 ± 1.0	-1.2	NSD	20
8 G	11.3 ± 1.1	11.5 ± 1.1	2.0	0.47	20
10 G	13.8 ± 1.5	14.5 ± 1.7	4.8	0.01	60
Peak Chest (G)					
6 G	8.2 ± 1.4	7.6 ± 0.9	-7.6	0.29	20
8 G	11.4 ± 1.2	10.8 ± 1.2	-5.6	0.05	20
10 G	14.3 ± 2.2	13.1 ± 1.3	-9.2	≤ 0.01	60

Head acceleration response data have noticeably less variability than the T1 data. Peak head acceleration, in Figure 4, rises uniformly as the input acceleration increases. Head accelerations experience the largest difference between male and female data in the 10 G test at 4.8%. Differences in the 6 and 8 G tests are minimal. With little variability, the chest acceleration data shows a similar incremental increase in peak response from 6 to 10 G, as the head accelerations. Percent change between male and female data is more significant in the chest acceleration measurements with differences of -7.6%, -10.8% and –14.3% for the 6, 8 and 10 G tests, respectively.

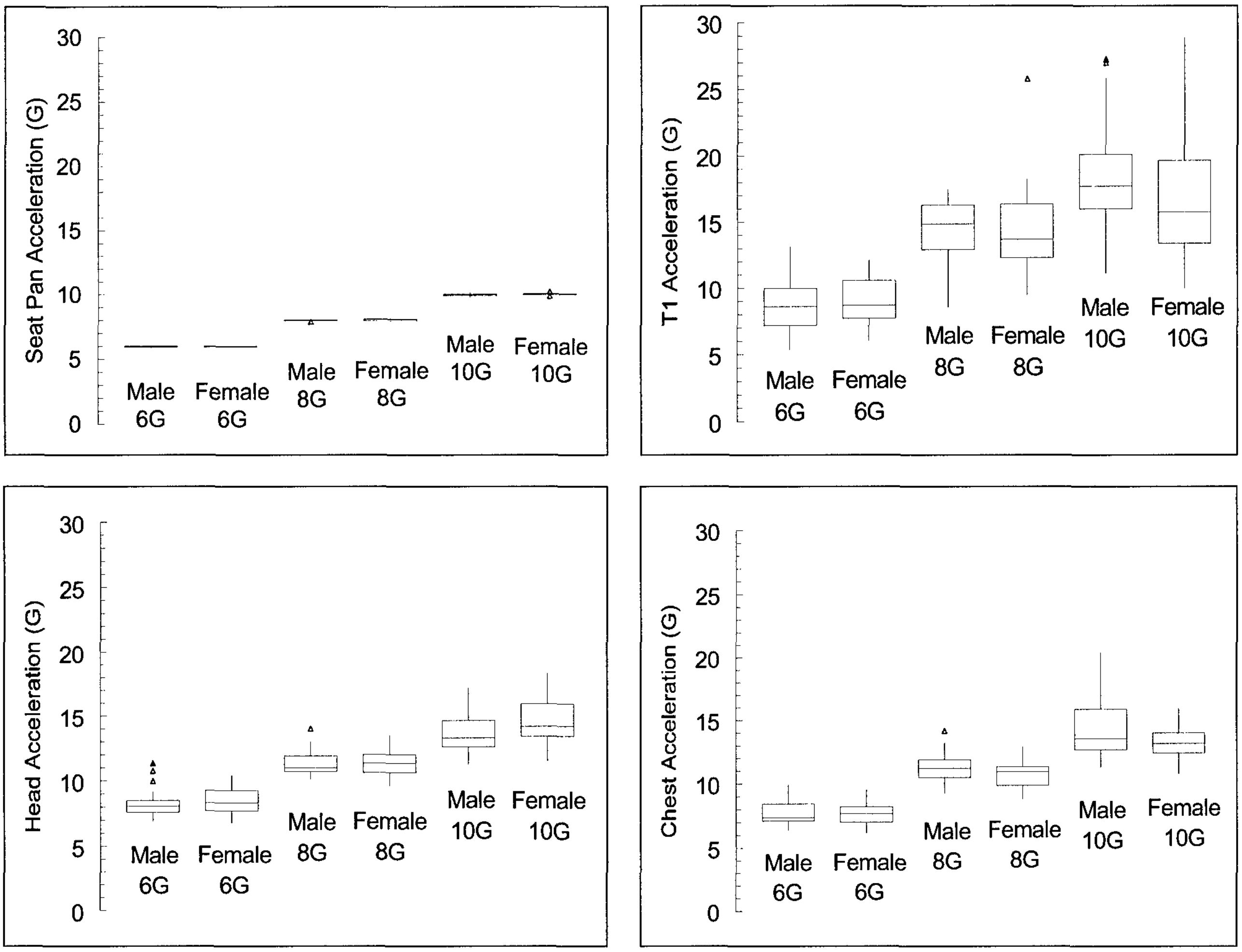

Figure 4. Peak acceleration data for all accelerometer locations at 6, 8 and 10 G, for male (n = 20) and female (n = 20) subjects. Each data set contains 20 tests, one per subject.

Several other key observations can be made in the data represented in Figure 4. First, acceleration response does not linearly increase with increasing input acceleration. This is demonstrated in Figure 5 where the acceleration difference between the nominal G load and the corresponding response is plotted for the three body locations. Two G increments in input do not associate with two G increments in the response. Moreover, the response does not increase in even increments but more in an exponential manner. Tests exceeding 10 G would give higher confidence in this observation. Another trend lies in the percent differences of the peak accelerations, as seen in Figure 6. The greatest percent differences are seen in the higher G tests. The difference between male and female seems to grow with increasing G load. Again, more tests of higher G loads would be helpful.

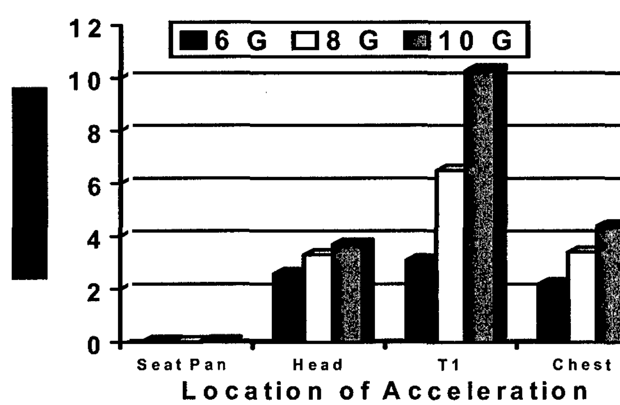

Figure 5. Difference between nominal G value and the measured G value at each accelerometer location, for male subjects. Female subjects give similar trends.

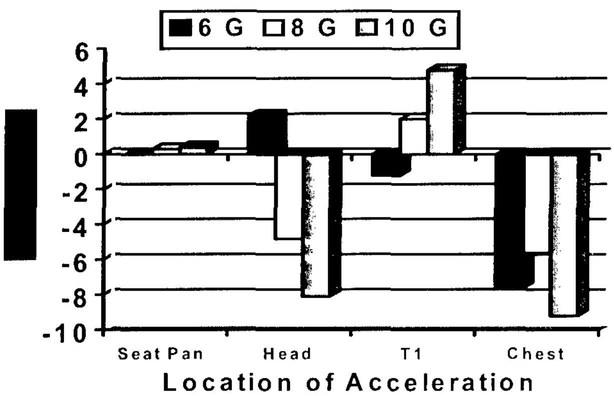

Figure 6. Percent difference between male and female peak accelerations for each accelerometer location.

Time-of-Peak Acceleration

In Figure 8 on the following page, time-of-peak acceleration is displayed for the peak acceleration data of Figure 4. Table 4 gives the data in numerical format. In general, the times-of-peak decrease as the input acceleration increases, since the boxes step down in time from 6 to 10 G's. This is expected since increasing input acceleration decreases rise time, giving less time for the seat-occupant to react to the impact. One interesting anomaly occurs in the 6 G data due to a delay in the time-of-peak. This is a result of a flattened seat pan acceleration curve, shown in Figure 7. Seat pan acceleration pulses of higher G's usually peak immediately after rises from the initial 0 G state. The 6 G pulse hesitates in its peak time, thereby driving the 6 G test median values of time-of-peak at least 10 ms later than expected. This hesitation is a function of the shape of plunger used to create the impact, as well as the amount of acceleration imparted on the seat-occupant.

Variability in the times-of-peak is similar to that in the peak accelerations. Overall, the seat pan has the smallest variation with only the female 6 G test differing significantly from the other data sets. This is likely due to the 6 G test anomaly already discussed. Concerning T1 times-of-peak, a 5 ms decrease for each additional 2 G's of input acceleration is observed. The greatest percent change between genders is 7.7% in the 8 G test. The differences in the other tests are negligible.

The times-of-peak in the head data also decrease with increasing acceleration. Male and female results are very similar with all time-of-peak differences less than 3.6%.

The chest data is similar with relatively small differences in time-of-peak response between male and female subjects. The greatest percent change between genders is 4.1% in the 10 G test. In general, time-of-peak in the chest decreases as the input acceleration increases.

Table 4. Time-of-peak data ($\pm \sigma$) at the three acceleration levels for male and female subjects.

Measured Parameter	Males	Females	% Diff	p-value	n
Seat -Time of Peak (ms)					
6 G	92.9 ± 14.2	94.6 ± 13.1	1.8	NSD	20
8 G	77.4 ± 10.1	73.9 ± 3.7	-4.5	0.02	20
10 G	66.6 ± 1.3	66.7 ± 1.4	0.2	≤ 0.01	60
T1-Time of Peak (ms)					
6 G	82.6 ± 16.2	83.5 ± 10.8	1.1	0.29	20
8 G	74.2 ± 11.3	79.9 ± 12.1	7.7	0.05	20
10 G	73.4 ± 11.3	75.1 ± 14.0	2.3	≤ 0.01	60
Head-Time of Peak (ms)					
6 G	92.1 ± 10.6	91.6 ± 4.3	-0.5	NSD	20
8 G	80.6 ± 7.7	83.5 ± 4.1	3.6	0.14	20
10 G	76.1 ± 7.1	77.1 ± 4.1	1.3	≤ 0.02	60
Chest-Time of Peak (ms)					
6 G	96.3 ± 6.4	97.1 ± 6.4	.8	NSD	20
8 G	85.8 ± 7.1	88.6 ± 6.2	3.2	0.17	20
10 G	81.2 ± 6.9	84.7 ± 6.7	4.1	0.01	60

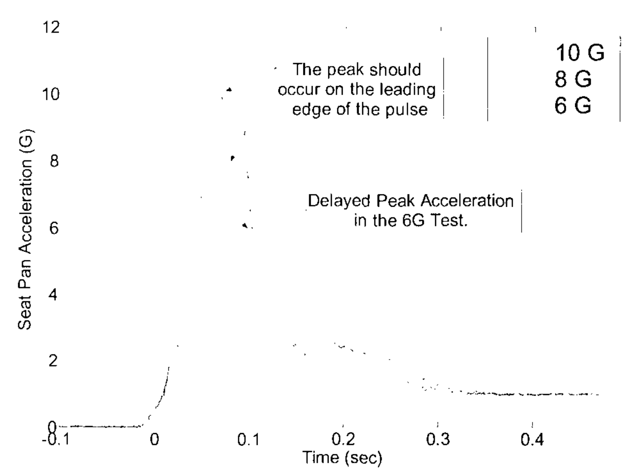

Figure 7. A demonstration of the delayed time-of-peak in the seat pan acceleration response curve for a 6 G test. The 8 and 10 G tests show an ideal peak on the leading edge of the pulse.

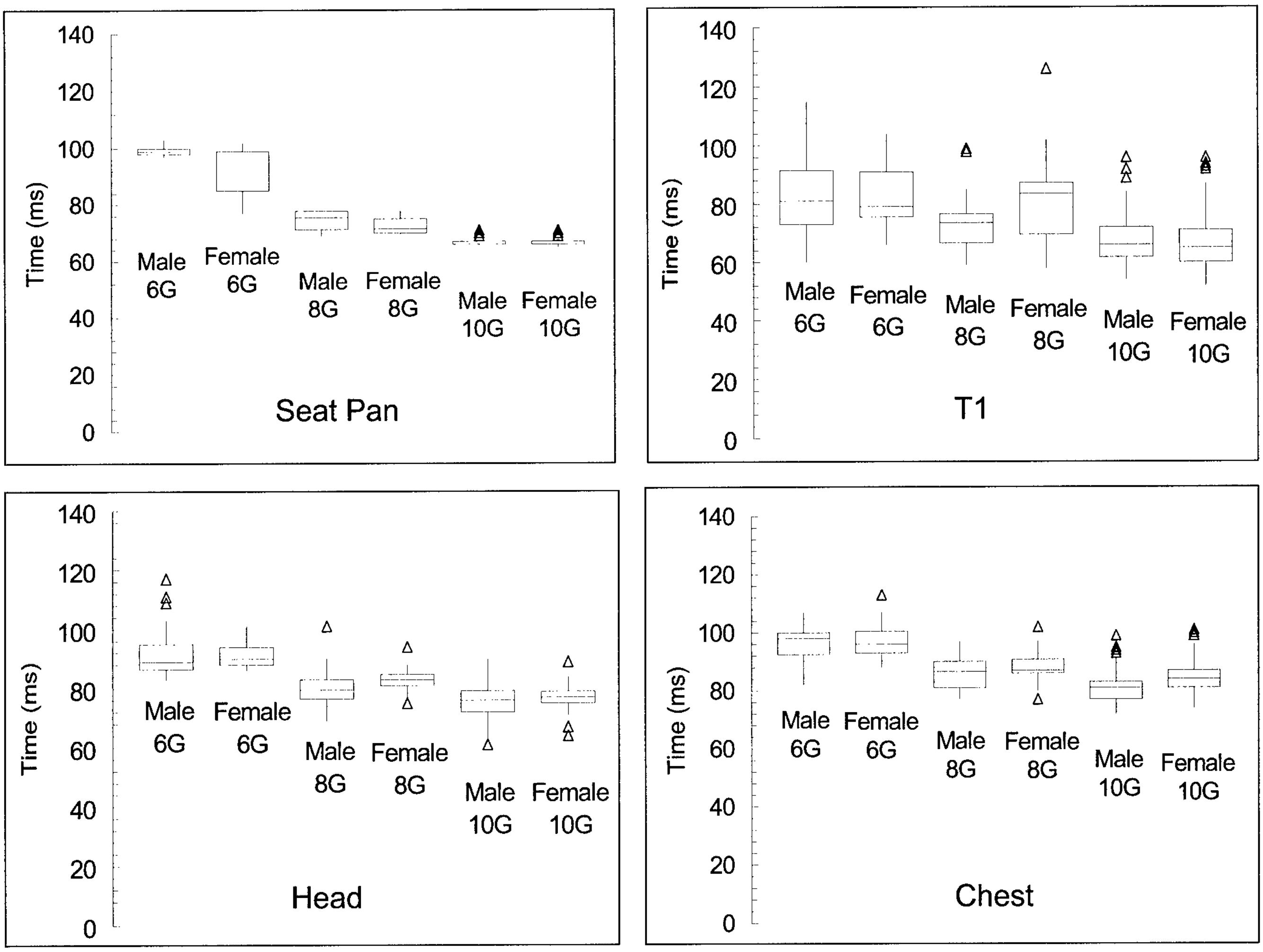

Figure 8. Time-of-peak data for all accelerometer locations at 6, 8 and 10 G for male (n = 20) and female (n = 20) subjects. Each data set contains 20 tests, one per subject.

Just as the input acceleration and corresponding peak acceleration responses correlate nonlinearly, so do the times of peak from one G load to another. Figure 9 illustrates the time-of-peak differences between 6, 8 and 10 G's. The difference in times decreases rapidly with higher G loads. The greatest difference is experienced in the head with time values changing from 11.5 to 4.5 ms, from 6 to 10 G. The smallest difference is found in the rigid seat pan.

Figure 10 displays the percent differences between genders at the four locations of measurement. Most differences are insignificant, with the largest found in the T1 at 7.7%. As in the peak acceleration data, the time-of-peak differences have standard deviations between 30% and 75% in the data sets. Therefore, no significant differences are seen between male and female response.

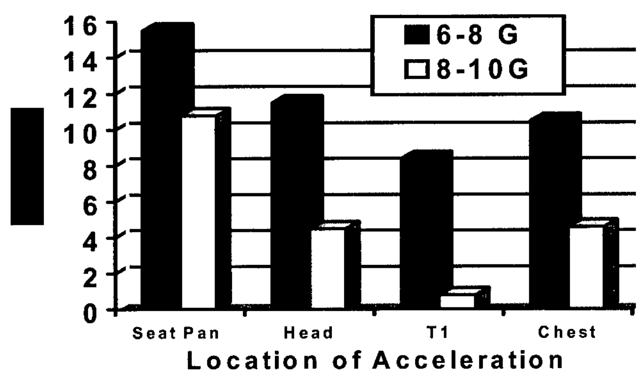

Figure 9. Difference of time-of-peak between the 6 and 8 G tests and the 8 and 10 G tests, at each accelerometer location, for the male subject. Female subjects give similar trends.

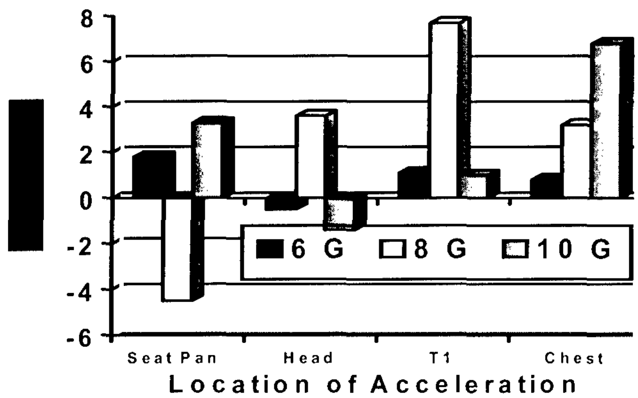

Figure 10. Percent difference between male and female times-of-peak for each accelerometer location.

Composite 10G Tests

A more thorough analysis is conducted for the 10 G VDT test data. Since three different 10 G tests were carried out for each subject, a total of 120 tests are available. Subjects were tested only once for the 6 and 8 G tests. More tests were conducted at the 10 G level since it closely mimics the acceleration experienced during an actually aircraft ejection. However, the acceleration level is still at a level that is considered to be non-injurious.

Figure 11 illustrates the composite 10 G data sets in the various locations of acceleration measurements. The locations are arranged in the chronological order in which they peak. The seat pan, acting as the input acceleration to the body, is first while the chest acceleration is fourth as it peaks last. The first observation is in the variability of the data. The seat pan has relatively no variability while the T1 data varies most, as seen in the comparison of the multi-G tests earlier. Head and chest acceleration vary by a nearly equal amount. Tables 3 and 4 give numerical representation of this data. As explained earlier, the T1 data varies greatly due to the difficulty in properly securing the accelerometer to the human upper back.

In Figure 12, time-of-peak measurements are characterized for the 120 data sets of the 10 G test. The most significant trend is the order of peaking in the various locations of the acceleration measurements. Table 4 also details this phenomenon. First to peak is the seat pan acceleration, followed by the T1, head and then chest. Since the thoracic spinal region and the chest are in the same area vertically, it is expected that the two would have similar peaking times. The delay in the chest may be due to the elastic properties of the viscera mass inside the thoracic cavity.

The percent difference (absolute) between males and females of the 120 data sets of 10 G tests is shown in Figure 13, with uncertainty. Figure 13 compares peak acceleration differences, with no difference higher than 10%. When taking uncertainty into account, the actual difference between male and female peak acceleration might not exceed 4% in any location.

Figure 13 also compares time-of-peak differences, with no difference higher than 4%. Since the differences are small and the uncertainties are relatively large, little difference is found between male and female time-of-peak acceleration. Error-adjusted differences do not exceed 2.5% in any location.

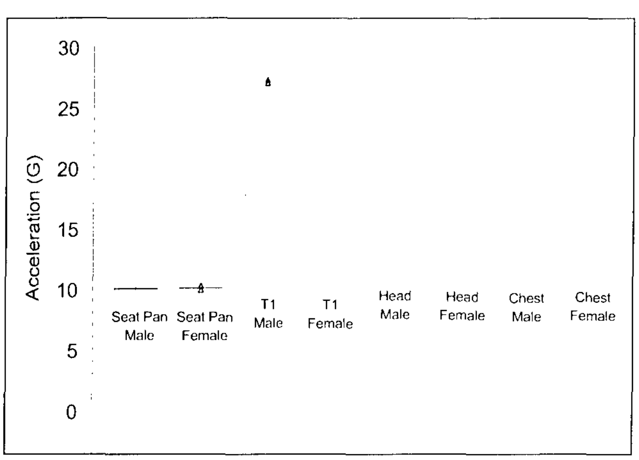

Figure 11. Peak acceleration data of the 120 data sets of 10 G tests for male (n = 20) and female (n = 20) subjects.

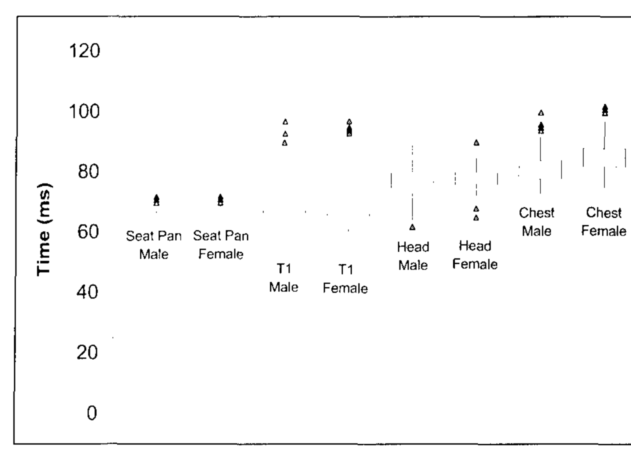

Figure 12. Time-of-peak data of the 120 data sets of 10 G tests for male (n = 20) and female (n = 20) subject

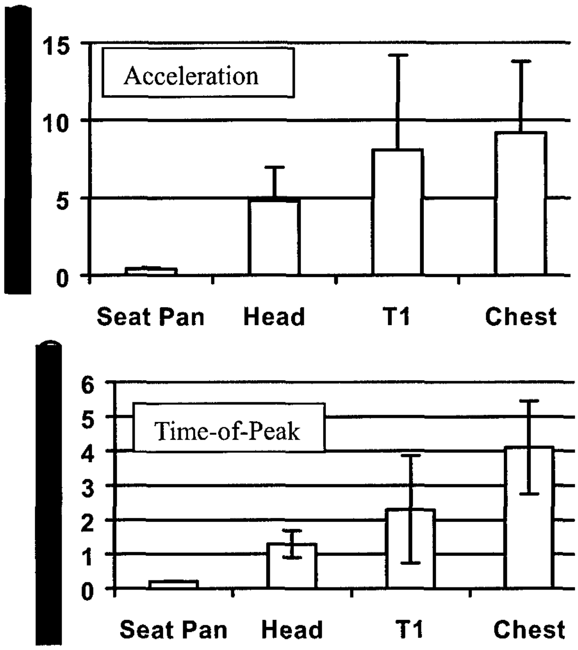

Figure 13. Percent difference in peak acceleration and time-of-peak for 120 data sets at 10 G, for male (n = 20) and female (n = 20) subjects. The average difference and corresponding uncertainty are plotted for each location.

The 10 G acceleration data has also been correlated with two important anthropometric parameters, mass and sitting height. Scatter plots of peak accelerations at each of the four accelerometer locations, with respect to the mass and sitting height, are shown in Figures 14-17 (pp. 11-12), for each of the subject tested. Three points per subject in each plot represent the values of peak acceleration or time-of-peak in three different 10 G tests. Correlations are sought between the anthropometric parameters and the respective peak acceleration and time-of-peak for both, male and female subjects, and as a collective group. Table 5 is a collection of r-values gathered from the scatter plots in Figures 14 and 15. No significant correlation are made between subject mass and peak acceleration or mass and time-of-peak. The best correlation is in the seat pan acceleration (r = -0.46).

Sitting height is another important parameter as it is closely related to spinal length. Table 6 shows the r-values gathered from the scatter plots in Figures 14 and 15. As with subject mass, however, no significant correlations are found between sitting height and peak acceleration or sitting height and time-of-peak. The best correlation is, again, in the seat pan acceleration (r = 0.57).

Table 5. Correlation coefficients for scatter plots in Figures 14 and 15, relating subject mass to peak acceleration and time of peak.

Measured Parameter	Males *n = 20*	Females *n = 20*	Combined *n = 40*
r			
Peak G-Seat	-0.42	-0.41	-0.46
Peak G-T1	-0.01	0.19	0.16
Peak G-Head	0.02	-0.21	-0.20
Peak G-Chest	-0.06	-0.10	0.21
Time of Peak-Seat	0.08	0.04	0.03
Time of Peak-T1	-0.02	0.08	-0.04
Time of Peak-Head	0.12	0.20	0.01
Time of Peak-Chest	0.42	-0.14	-0.07

Table 6. Correlation coefficients for scatter plots in Figures 16 and 17, relating subject sitting height to peak acceleration and time of peak.

Measured Parameter	Males *n = 20*	Females *n = 20*	Combined *n = 40*
r			
Peak G-Seat	0.24	0.05	0.57
Peak G-T1	-0.11	-0.08	0.03
Peak G-Head	-0.15	0.24	0.08
Peak G-Chest	-0.26	-0.07	0.10
Time of Peak-Seat	0.04	0.15	0.09
Time of Peak-T1	0.003	0.003	-0.04
Time of Peak-Head	-0.06	0.10	0.05
Time of Peak-Chest	0.19	0.13	-0.05

CONCLUSIONS

An analysis of laboratory data from vertical deceleration tower tests is presented in this study. Specifically, male and female spinal responses to aircraft ejection-like accelerations are compared. In general, it is concluded that male and female spinal response is remarkably similar in vertical impacts. The reason for this similarity, despite their anatomical differences, will be investigated in a future study. The following, specific conclusions can be drawn from this experimental data analysis:

1. As input acceleration increases from 6 to 10 G, (a) peak acceleration response increases nonlinearly in each region and (b) time-to-peak decreases nonlinearly in each region.
2. Time-of-peak is observed to occur in the following specific order: seat pan, T1, head and then chest. This order occurs regardless of the magnitude of input acceleration.

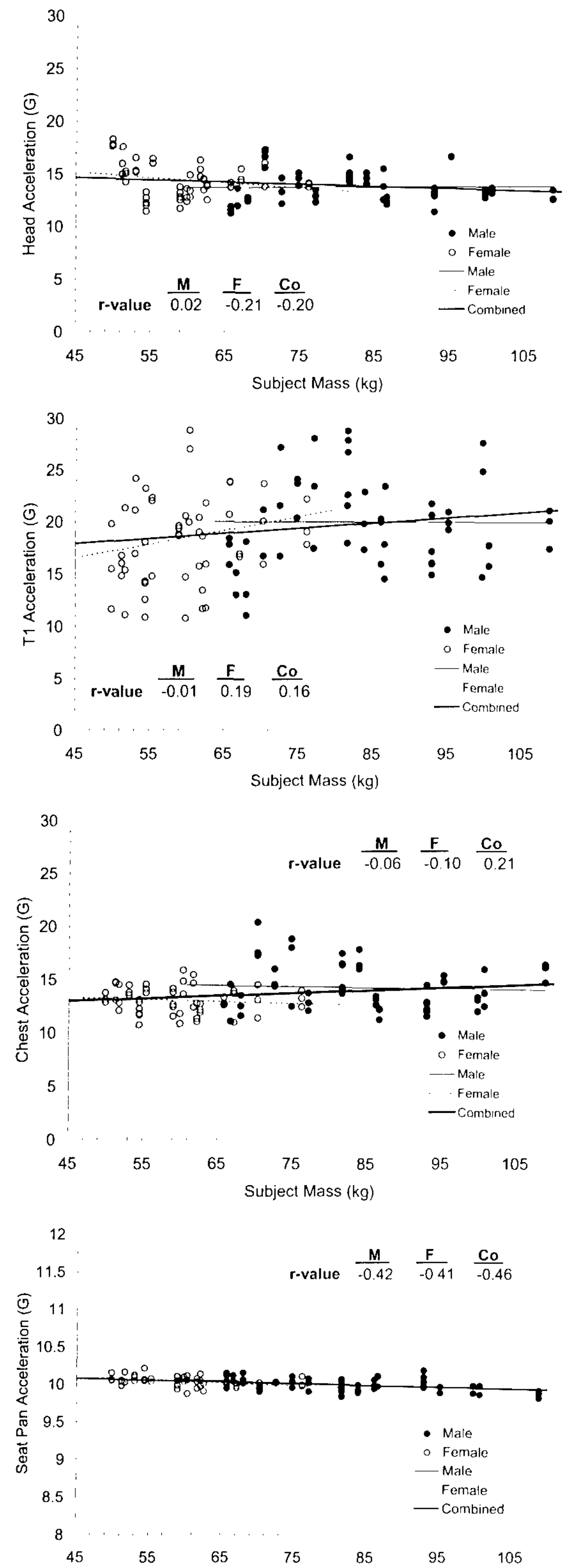

Figure 14. Peak acceleration data for 120 VDT tests at 10 G, with respect to subject mass for male (n = 20) and female (n = 20) subjects.

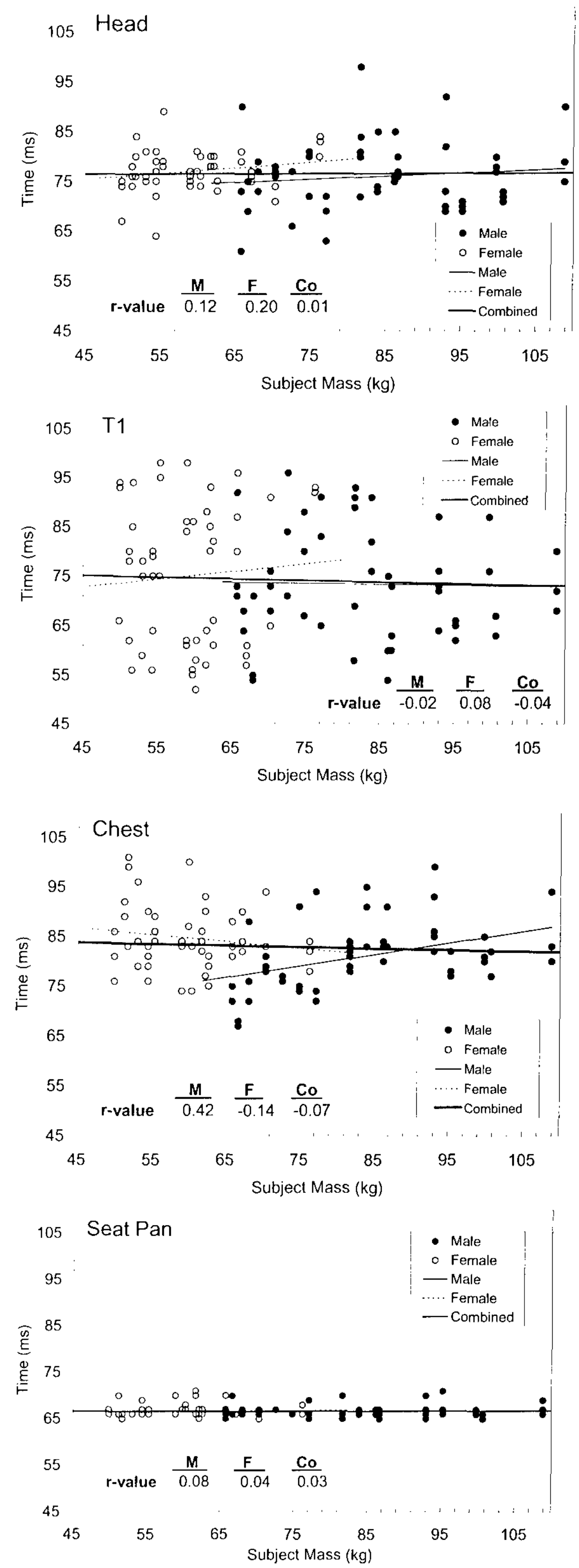

Figure 15. Time-of-peak acceleration data for 120 VDT tests at 10 G, with respect to mass height for male (n = 20) and female (n = 20) subjects.

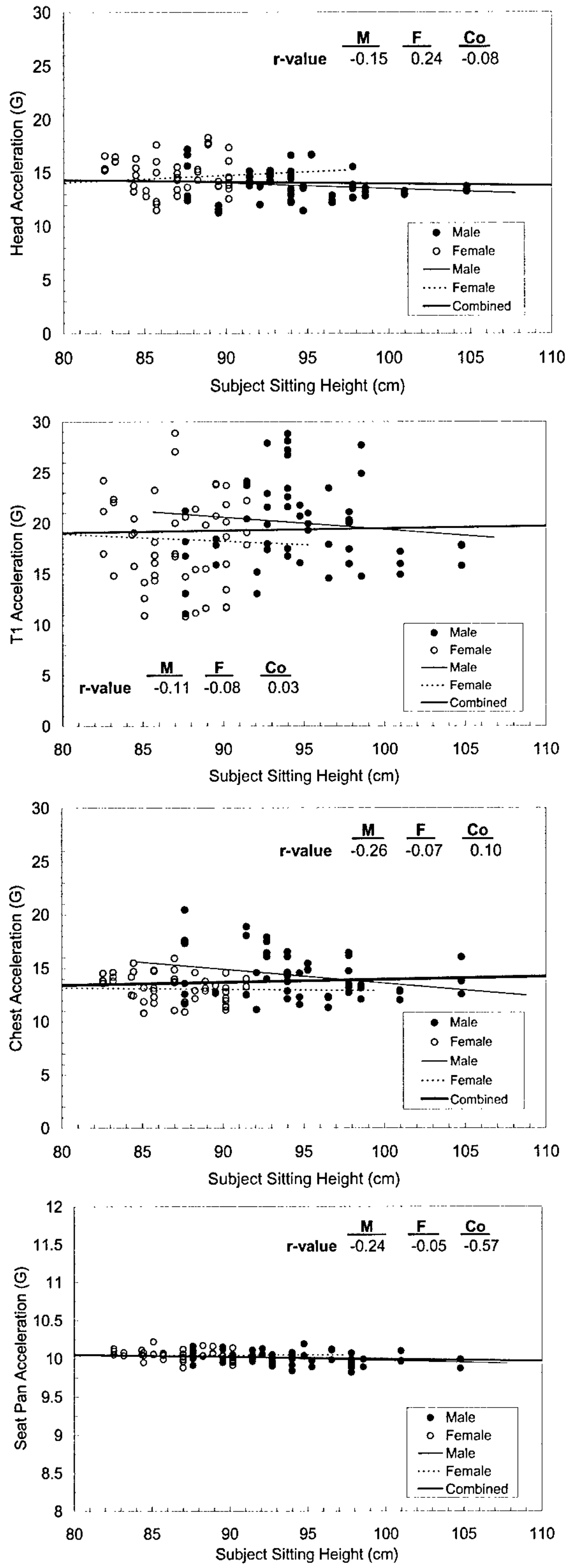

Figure 16. Peak acceleration data for 120 VDT tests at 10 G, with respect to subject sitting height for male (n = 20) and female (n = 20) subjects..

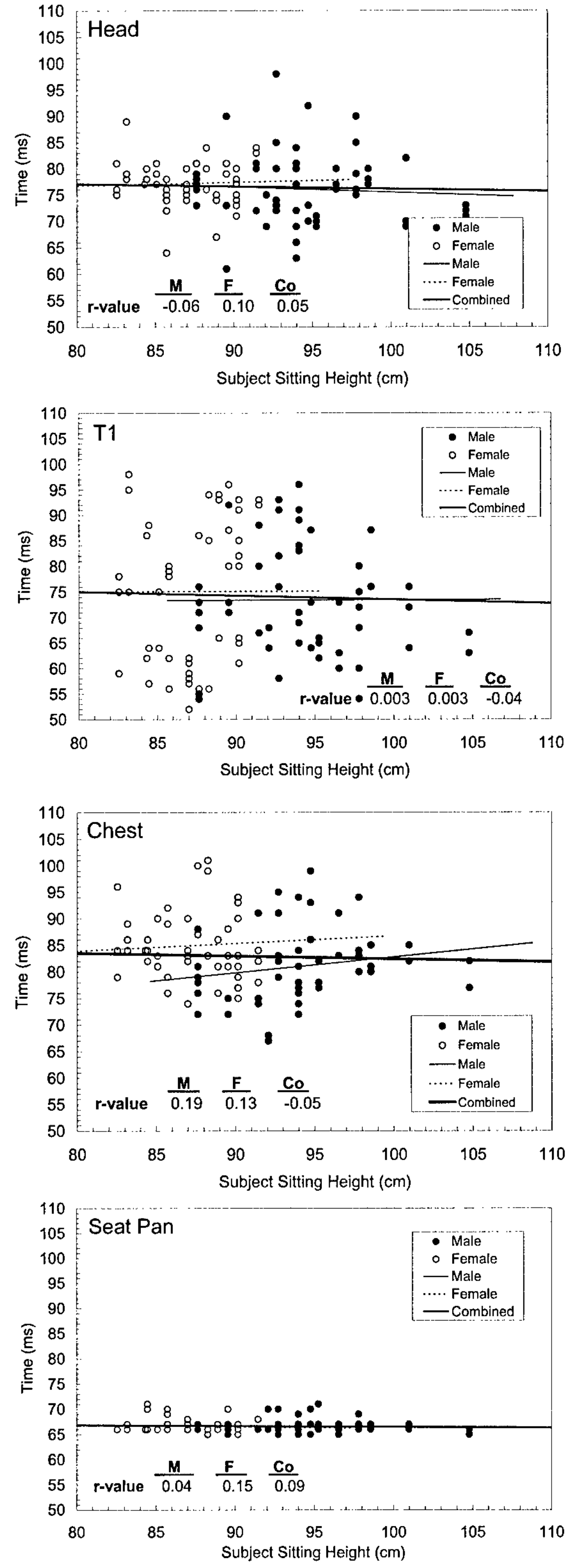

Figure 17. Time-of-peak acceleration data for 120 VDT tests at 10 G, with respect to subject sitting height for male (n = 20) and female (n = 20) subjects.

3. As input acceleration increases from 6 to 10 G, (a) peak acceleration response increases nonlinearly in each region and (b) time-to-peak decreases nonlinearly in each region.
4. Time-of-peak is observed to occur in the following specific order: seat pan, T1, head and then chest. This order occurs regardless of the magnitude of input acceleration.
5. A significant correlation (r = 0.84) was found between subject mass and sitting height.
6. Weak to no correlations are found between subject sitting height and peak acceleration response or sitting height and time-of-peak for each of three subject groups: male, female and combined.
7. Weak to no correlations are found between subject mass and peak acceleration response or mass and time-of-peak, for each of three subject groups: male, female and combined.
8. Among 120 VDT tests at 10 G, the greatest percent difference in peak acceleration between male and female subjects is in the chest at 9.2%, followed by the T1 and head at 8.1% and 4.8%, respectively. With uncertainty, however, the difference between male and female values might be less than 4% at any location. Seat pan acceleration difference was negligible at 0.4%. Even smaller differences between genders are found in the times-of-peak ($\leq 2.5\%$).
9. Although males and females have similar spinal responses at equal laboratory G-loads, lower-mass-females will still experience more G-load in an actual ejection, based on their typical lower mass alone. This factor must be taken into account when calculating probability of spinal injury among genders.

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David B. Hamlin is originally from Tyler, Texas. After completing a B.S. inMechanical Engineering at the University of Colorado-Boulder, he was commissioned as a Surface Line Officer in the U.S. Navy. After serving on a destroyer and aircraft carrier, he completed a 3-year shore tour in the Joint Information Operations Center (JIOC) at Kelly Air Force Base, San Antonio, Texas. In January of 2000, he entered the Graduate School of The University of Texas at San Antonio to pursue a Master of Science degree in Mechanical Engineering. He has since left active duty military in order to join the civilian sector as a professional engineer.

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